DETECTION OF OCEAN MINES USING ULTRA-SENSITIVE OPTICAL FIBER MAGNETIC FIELD SENSORS

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LONG-TERM GOAL

This Phase I Small Business Technology Transfer Research Program (STTR) is a 6 month effort by a team consisting of Fiber & Sensor Technologies (F&S) and its subcontractors, Fiber & Electro-Optics Research Center (FEORC) at Virginia Tech, Blacksburg, VA and Litton Poly-Scientific of Blacksburg, VA. The objective of the program is to develop low-cost, portable, fiber optic gradiometers capable of sensitive magnetic field gradient detection for shallow water mine detection and classification. The fiber optic gradiometer has advantages over existing gradiometer mine detection technology including wide operating temperature range, low power consumption, and small size/low weight. The small size/low weight and low power consumption of the device will allow remote mine detection via manned or unmanned remote control reconnaissance aircraft. Potential commercial applications of this technology exist in traffic monitoring sensors for axle counting and vehicle classification, intrusion detection and surveillance, non-destructive testing, and geophysical prospecting.

SCIENTIFIC OBJECTIVES

Magnetometers have found numerous applications in military and industry. By detecting the ambient magnetic field, objects can be located and classified such as enemy submarines and mines. They have found wide use as non-contact switching devices in manufacturing applications. Magnetometers provide advantages over other object location approaches because they are passive and their signal is not affected by non-ferrous objects. Gradiometers provide information on the change in the magnetic field over some distance (dB/dx) or gradient, and are capable of higher sensitivities since the noise induced by the earth's magnetic field variations is common mode rejected. The increased sensitivity and resolution of gradiometers allow their use in geophysical surveying and archeology, along with military applications such as submarine and mine detection and classification. Gradiometers complement acoustic and optical methods for mine hunting in shallow water environments where high acoustic or optical background clutter and attenuation limit operation of these devices. This program is focused on demonstrating the feasibility of a fiber optic vector magnetometer configuration which can be easily integrated into a 5 element gradiometer for bearing and magnetic moment detection of ferrous mines (Wynn, et al., 1975).

APPROACH

F&S is using an extrinsic Fabry-Perot interferometer (EFPI) configuration with magnetostrictive elements and silicon micromachined substrates to create a temperature insensitive device to detect the magnetic field signatures of buried, tethered, and floating ferrous mines. The optically

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based sensor has ultra-high sensitivity and does not perturb the local magnetic field due to the dielectric nature of the sensor components.

The fiber optic magnetometer/gradiometer exploits the many advantages fiber optic sensors over conventional electrical sensors. Fiber optic sensors are small size and low weight, have a large bandwidth and multiplexing capabilities, and are immune to electromagnetic interference (EMI). EMI immunity combined with low optical loss fiber allows remote operation of the sensors at distances of kilometers. In addition, interferometric type fiber optic sensors are based on the constructive and destructive interference of light at sub-micron wavelengths, which provides excellent sensitivity. The use of optical fiber sensors promotes tremendous time and cost savings by employing technologies extensively used in the communications industry.

The movements in the magnetostrictive element are monitored using an EFPI configuration. The EFPI is based on the combination of two light waves with a path induced phase change between them. As seen in Figure 1, the EFPI consists of an input/output fiber, and a reflector fiber aligned by a hollow core silica tube (Kent, et al., 1991). The laser diode light arrives at the sensor head and a portion is reflected off the fiber/air interface (R1). The remaining light propagates through the air gap (S) and a second reflection occurs at the air/fiber interface (R2). R1 is the reference reflection while R2 is the sensing reflection. These two light waves interfere constructively or destructively based on the path length traversed by the sensing reflection, and travel back through the coupler to the detector. The second output of the coupler is shattered to prevent reflections from interfering with the EFPI signal. Small movements in the magnetostrictive material cause a change in the gap distance, which changes the phase difference between the sensing and reference waves. Both capillary tube and silicon V-groove alignment schemes are being investigated to create a temperature insensitive device. The cross-sectional diameter of the device can be as small as 250 μm.

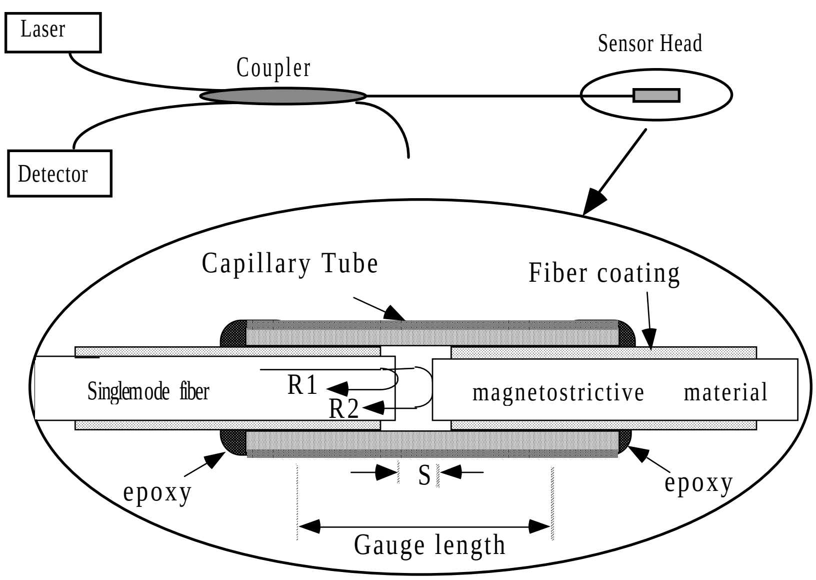


Figure 1. The Extrinsic Fabry-Perot Interferometer in a Magnetometer Configuration

WORK COMPLETED

The following is a brief list of the technical accomplishments during the first part of the program:

1. F&S and FEORC researchers investigated available materials for magnetic field detection;
2. F&S designed methods for signal stabilization demodulation;
3. Litton Poly-Scientific manufactured silicon V-grooves;
4. F&S and FEORC researchers manufactured and tested several single-point fiber optic magnetometers;
5. Temperature compensation designs were manufactured and tested; and
6. Market contacts were pursued for Phase II commercialization plan.

RESULTS

F&S and FEORC researchers have constructed numerous single axis fiber optic magnetometers for temperature and magnetic field response characterization. Tests were conducted on a magnetometer to determine the minimum detectable magnetic field. The test set-up is shown in Figure 2. The 5 cm long magnetometer was placed in the center of a coil that was energized using a current source. A handheld F.W. Bell gauss meter was used to determine relative levels of magnetic field. The resolution on the meter was 10,000 nT. A plot of the response of the sensor is shown in Figure 3. The response of the magnetometer was measured as 18 μV/nT. With a 0.63 mV RMS noise level, the resolution of the device is 35 nT. F&S is currently investigating methods to reduce the electronic noise level and achieve sub-nanotesla resolution.

To demonstrate the metal detection capabilities of the device, a small ferrous object was brought close to the sensor head and the output monitored. Figure 4 shows the response of the fiber optic magnetometer when the object was brought close and passed over the device. The ferrous object perturbs the static magnetic field surrounding the sensor head, and causes a deflection in the magnetostrictive element.

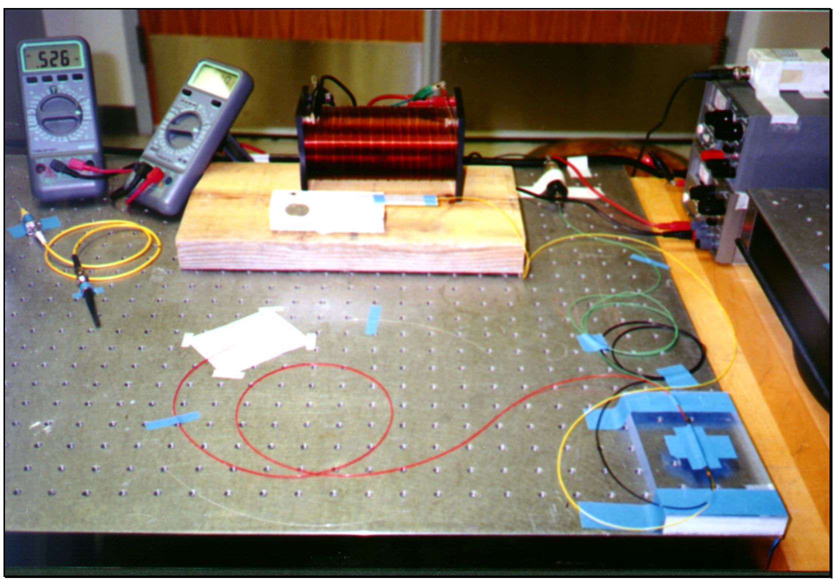


Figure 2. Test Set-up for Magnetometer Characterization

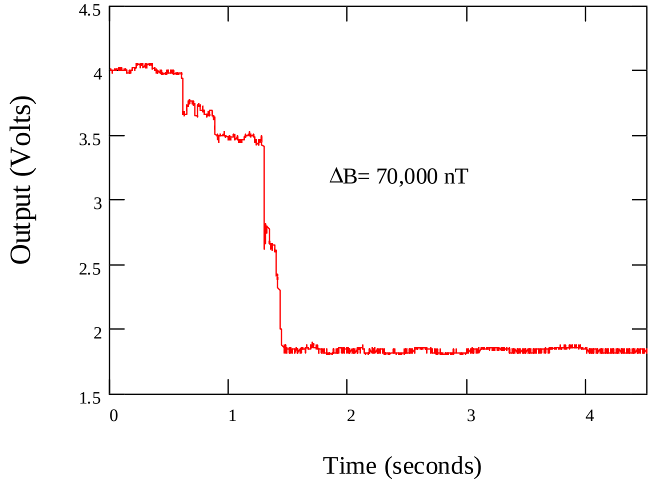
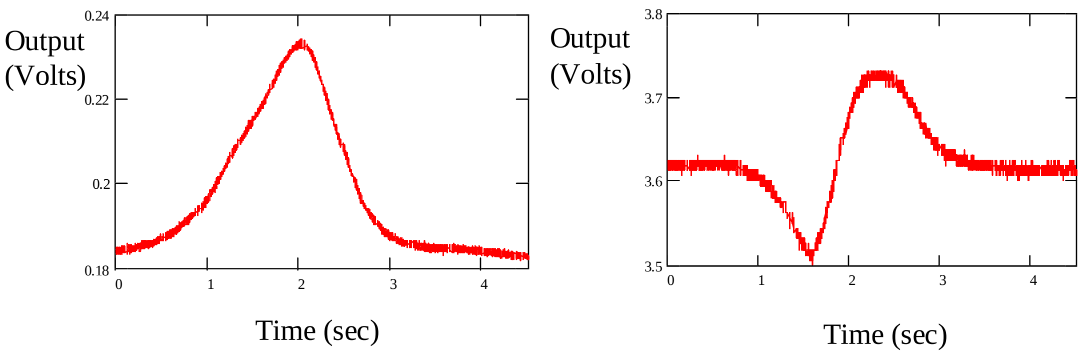


Figure 3. Response of Magnetometer to a 70,000 nT Change in Field. Discontinuities in the Output are Due to the Current Source Potentiometer that is used to Drive the Coil



3 lb ferrous object brought to 1” from sensor head and removed

3 lb ferrous object passed 1” over sensor head

Figure 4. Response of Magnetometer when a Small Ferrous Object is Brought Close to the Sensor Head

IMPACT/APPLICATION

The fiber optic magnetometer will complement existing acoustic and optical methods of mine detection and classification in shallow water environments where high acoustic or optical background clutter and attenuation limit operation of these devices. F&S envisions large, near-term commercial product opportunities in military and industrial applications. Primary near-term commercial applications are in nondestructive object location and classification for geophysical surveying, environmental remediation, industrial manufacturing, and civil engineering uses. Additional applications include vehicle detection and classification in intelligent transportation systems and sensors for intrusion detection and surveillance systems.

TRANSITIONS

F&S is evaluating the performance tradeoffs of the 5 element gradiometer based on the results of the Phase I single axis magnetometer design and testing. Areas needing improvement and further development will be identified for investigation during the Phase II project. F&S is also preparing a commercialization plan and identifying sources for possible follow-on funding to support product commercialization during Phase III. Follow-on funding support has been pledged by FiberCore Technologies. F&S has already identified potential customers at Boeing Aerospace and the Federal Highway Department.

RELATED PROJECTS

The United States Navy (USN) and United States Marine Corps (USMC) have seen an increased need for war fighting capabilities on the littoral front. Enemy mine placement remains an effective deterrence for amphibious operations and prevents rapid advancement of forces and limits their maneuverability (Smith, 1995). The USN has developed gradiometers for mine detection under the Magnetic/Acoustic Detection of Mines program and in the current Mine Reconnaissance /Hunter program (Lathrop, 1995). The current gradiometer development is based on superconducting quantum interference devices (SQUID) (Clem, 1995; Lenz, 1990). The SQUID platform provides excellent sensitivity at the cost of increased maintenance and limited continuous operational time because of the cryogenic cooling requirements of the device. Results from this project are expected to compliment the SQUID platform and extend the Navy's mine detection capability.

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